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Three Phase Power Flow Calculation of Weak Loop Distribution Network with Multiple Distributed Generators

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Abstract: As a beneficial supplement to centralized power generation(PG), distributed PG has attracted more and more attention in the world because of its many advantages, such as safety and reliability, low pollution, energy saving and economy, flexible installation location and so on. At present, many scholars at home and abroad have analyzed and studied the power flow algorithm of distribution network with distributed generation(DG) from different angles, and have made some achievements. In this paper, Three phase power flow calculation(TPPFC) of weak loop distribution network(LDN) with multiple distributed generators is analyzed and studied. The influence of human DG on power flow of distribution network and the modeling of various DG and load are analyzed; The three-phase power flow(TPPF) algorithm is discussed. Finally, through the simulation experiment of the TPPFC of the weak LDN with multiple distributed generators, the application of distributed generators to the distribution system(DS) is discussed. The simulation calculation of the IEEE-14 node DS and the ieee-33 node DS with distributed generators is accurate and fast.

1. Introduction

With the increasing attention of governments at all levels to the construction of smart grid, a large number of distributed power(DP) sources are incorporated into the grid. Due to the strong randomness of distributed PG output, the power flow of the power grid becomes difficult to predict. The power flow of computing system is the foundation of power grid construction and dispatching, and it is very important. Traditional power flow calculation methods, such as Gauss method, Newton Raphson method and P-Q decomposition method, are difficult to meet the requirements, so new random power flow algorithm must be used for calculation. Based on the comparison and study of the existing stochastic power flow algorithms, this paper proposes TPPFC. The TPPFC of weak LDN with distributed photovoltaic sources is studied.

Many scholars at home and abroad have studied and analyzed the TPPFC of weak LDN with multiple distributed generators. Dobbe r considers the DS with multiple controllable distributed energy sources, and proposes a data-driven method to learn the control strategy of each distributed energy source, so as to reconstruct and simulate the solution to the centralized OPF problem from the separate local available information. To determine which nodes the distributed energy should communicate with to improve the reconstruction of its single strategy [1].

By studying the working principle and physical characteristics of photovoltaic cells, the active power output model of photovoltaic array is obtained, and combined with the maximum power point tracking control model, the active power output model of photovoltaic PG system is obtained. By studying the working principle and control method of the inverter, the reactive power output model of the photovoltaic PG system is established by using the state space average method[2]. The photovoltaic PG system is incorporated into the distribution network, and the power flow calculation model of the distribution network with distributed photovoltaic sources is obtained. A power flow calculation method based on three-phase distribution network is proposed. Based on the detailed analysis of the generation characteristics of DG, the application of DG in DS is discussed. At the same time, the influence of distributed photovoltaic sources on the voltage, transmission power and network loss of each node of the distribution network is also analyzed [3-4].

2. Weak Ring Distribution Network with Multiple DP Sources

2.1. Impact of Access of Distributed PG on Power Flow of Distribution Network

The access of DP makes the distribution network structure more complex. From the radial single power supply network structure to the multi power supply system with close contact with users, and the two-way flow may occur in the system. The power transmission in the line and the voltage of each node in the system will also change significantly, and some new node types will appear, It has a certain impact on the conventional power flow calculation method of distribution network [5-6].

2.2. Modeling of Various DP Sources and Loads

2.2.1. WPG

WPG (wind power for short) is a technology that converts wind energy into electric energy. After capturing enough wind energy, the wind turbine converts the mechanical energy into electrical energy through the rotation movement mode. This is the basic step of WPG system [7]. Small wind turbines can be used to solve the power consumption problems in remote mountain areas, islands, rural areas and other areas without electricity and lack of electricity, and can also make full use of local wind resources to achieve the goals of energy conservation, emission reduction and electricity cost saving [8].

Wind turbines are generally AGs, and the absorbed reactive power will have a significant impact on the power grid system, and the slip rate of the asynchronous motor, the voltage of each node of the system and other factors will have a certain impact on the reactive power absorption of the AG. Therefore, when the wind power is connected to the grid, the work of WPG and grid system should be well coordinated [9-10]. The simplified EC of AG is shown in Fig. 1.

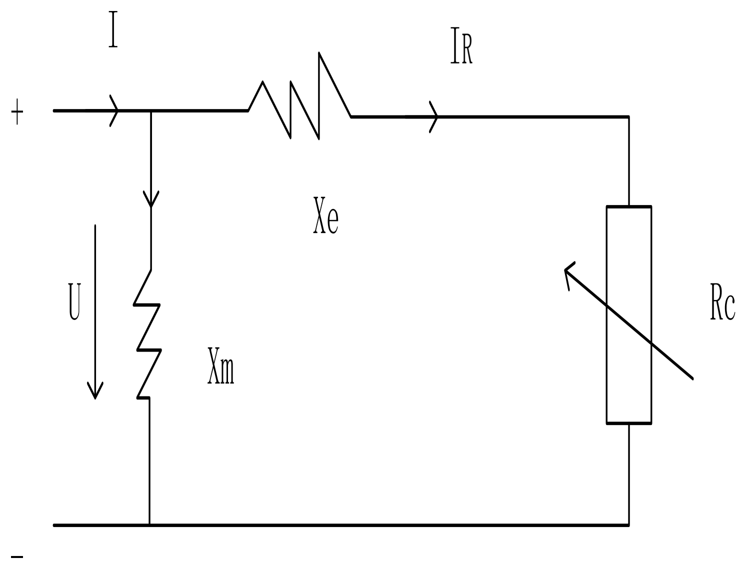

Figure 1. Simplified EC of AG

2.2.2. Fuel Cell Model

The electricity generated by the fuel cell is direct current. If it is to be incorporated into the power grid, it must be converted into alternating current by the voltage source inverter [11]. The EC of the fuel cell is shown in Fig. 2.

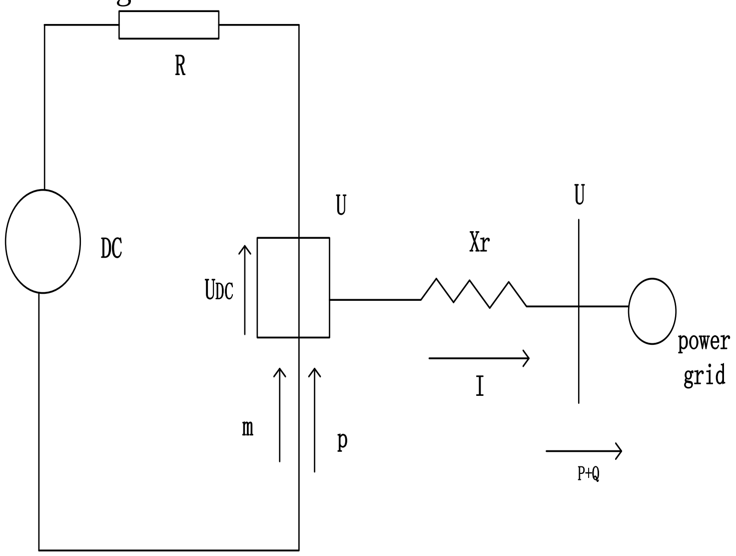

Figure 2. EC of fuel cell

The advantage of solar cells is that as long as there is a light source such as the sun or light, it can instantly generate electric energy, and the total amount of electric energy emitted is basically 1-20% of the light energy absorbed. Generally speaking, the stronger the light, the more electric energy will be generated. However, the photoelectric conversion efficiency of solar cells is only about 15%, and crystalline silicon has always been the main material of solar cells [12-13].

2.2.3. Model of Photovoltaic PG

Some parameters of solar photovoltaic cells will change during the operation, so as to better understand the factors affecting photovoltaic PG, maximize the efficiency of photovoltaic PG, and lay a foundation for further research on photovoltaic PG in the future; In order to realize the effective grid connection of photovoltaic cells, the inverter must be used to complete the conversion and control, so as to obtain the current or voltage control mode [14-15]. The latter is a PV node, which is a node with constant active power and voltage [16].

3. TPPFC

Generally, any parameter in the extended power flow equation is selected as the continuous parameter, which can be the load parameter or any one of the state variables e or F. Selecting appropriate continuous parameters can ensure the reliable convergence of continuous power flow calculation, and selecting inappropriate continuous parameters will lead to divergent calculation. When the system load level is relatively light, the load parameter can generally be selected as a continuous parameter [17]. This is because when the load level of the system is light, the system has strong voltage support capability, even in the load parameters.

In the case of large changes, the voltage change in the system is still relatively small. On the contrary, when the system load is close to the maximum limit, the slight change of the load will lead to the violent fluctuation of the system node voltage. At this time, when the load parameter is still selected as a continuous parameter, it will cause the divergence of the algorithm [18]. In the local parameterization method, continuous parameters need to be re selected at each step of the continuous power flow solution process. Generally, the quantity with the largest absolute value among the tangent quantities is selected as the continuous parameter, which can be expressed by the following formula:

$$s_r : |s_r| = \max\{|s_1|, |s_2|, \ldots |s_{me+1}|\} \tag{1}$$

Where: S1, s2sme + 1 is the tangent vector [De, DF, D λ] L.

The local parameterization method needs to add a construction equation in the correction link:

$$g(e, f, \lambda) = x_r - \tilde{x}_r = 0 \tag{2}$$

Where: XR represents the state variable (EF, λ) The r-th element in; XR is the estimated value of this state variable.

Injection current type three-phase continuous power flow algorithm: select local parameterization as the parameterization method, and select load parameters when calculating the next operating point of P-V curve from the original operating point of the system λ Is a continuous parameter. The tangent method is adopted for the estimation. Since it is based on the Newton Raphson method of injection current type, the expression is:

$$\begin{bmatrix} h11, h12, \dfrac{\delta\Delta m}{\delta\lambda} \\ H21, H22, \dfrac{\delta\Delta g}{\delta\lambda} \\ e_l \end{bmatrix} \begin{bmatrix} de \\ df \\ d\lambda \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \pm 1 \end{bmatrix} \tag{3}$$

$H_{11} = B - \frac{\delta\Delta m}{\delta e}$,$H_{12} = G - \frac{\delta\Delta m}{\delta f}$,$H_{21} = G - \frac{\delta\Delta m}{\delta e}$,$H_{22} = -B - \frac{\delta\Delta m}{\delta F}$,are Jacobian matrix blocks in conventional power flow calculation.

When making the first prediction according to the original operating point of the system, the load parameter is selected as the continuous parameter, and the direction of the tangent vector is selected as 1. This selection method is appropriate because the load always changes in an increasing manner when the continuous power flow is calculated from the original operation point. Solving equation (3) to obtain the tangent vector of the extended equation group, then the estimated solution of the state variable of the extended equation group can be expressed as:

$$\begin{bmatrix} \tilde{e} \\ \tilde{f} \\ \tilde{\lambda} \end{bmatrix} = \begin{bmatrix} e \\ f \\ \lambda \end{bmatrix} + \sigma \begin{bmatrix} de \\ df \\ d\lambda \end{bmatrix} \tag{4}$$

The correction link is solved by Newton method. The estimated solution obtained by the estimation link is taken as the initial value of Newton method and substituted into the extended power flow equation to obtain the true power flow solution. The specific iteration form is as follows:

$$\begin{bmatrix} \Delta g \\ \Delta h \\ x_r - \tilde{x}_r \end{bmatrix} = \begin{bmatrix} H_{11}, H_{12}, \dfrac{\delta\Delta H}{\delta\lambda} \\ H_{21}, H_{22}, \dfrac{\delta\Delta g}{\delta\lambda} \\ e_r \end{bmatrix} \begin{bmatrix} \Delta e \\ \Delta f \\ \Delta\lambda \end{bmatrix} \tag{5}$$

Like the conventional power flow calculation, the convergence judgment is required in the correction link. If the convergence conditions are met, the correction link is completed to obtain the true power flow solution and load parameters. Otherwise, the iterative operation needs to be continued. The calculation flow is shown in Figure 3.

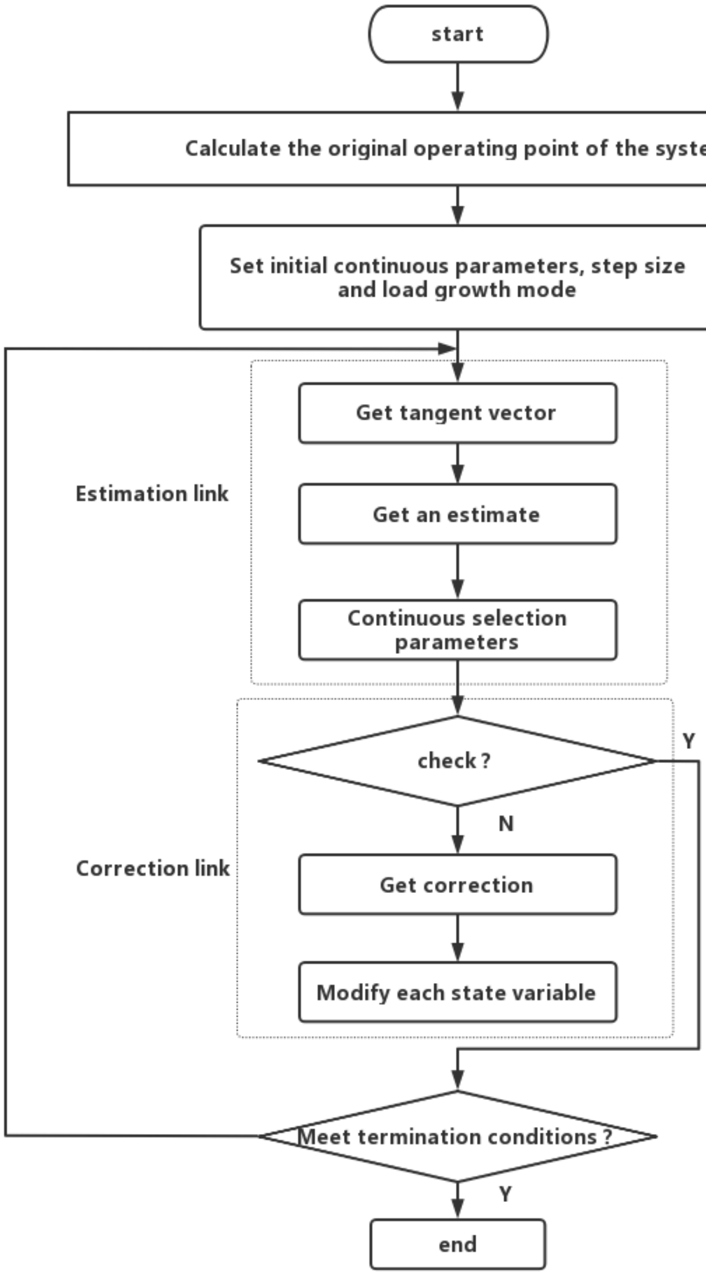

Figure 3. Calculation flow of three-phase continuous power flow algorithm

4. Simulation of TPPF in Weak LDN with Multiple Distributed Generators

The ieee-4 node system is adopted in this paper. The transformer adopts Dyn11 connection. The three-phase balanced active power load of a, B and C is 1800kW, the power factor is 0.9 (lag), and the neutral grounding impedance of the low-voltage distribution network is set to 0.4 Ω. Calculate the power flow under balanced load(BL) and unBL(UL) respectively, and the calculation results are shown in Table 1.

Table 1. Power flow under three-phase BL and UL

Node	Weight	Under BL/(V∠°)	Under UL/(V∠°)
2	ab	12334.1∠29.73	12344.6∠29.90
	bc	12350.0∠-90.38	12366.6∠-90.60
	ca	12322.0∠149.61	12259.7∠149.56
3	a	2238.6∠26.22	2334.2∠25.92
	b	2275.3∠-93.69	2328.5∠-91.96
	c	2255.6∠146.69	2073.9∠144.47
	n	13.0∠-129.34	92.8∠-34.18
4	a	1915.0∠21.03	2164.7∠24.69
	b	2057.3∠-98.41	2032.9∠-95.93
	c	1985.2∠140.83	1669.3∠131.24
	n	13.0∠50.66	92.8∠145.82

It can be seen from table 1 that the neutral point voltage is not zero under BL and UL. The existence of neutral point voltage under BL is caused by the three-phase asymmetry of line parameters. The neutral point voltage under UL is significantly higher than that under BL. There are three-phase load imbalance and three-phase parameter asymmetry in the medium and low voltage distribution network. It can be seen that the accurate result of power flow cannot be obtained if the neutral point voltage is assumed to be zero in Kron's simplification, and it does not conform to the reality. Therefore, it is very necessary to keep the neutral line in the power flow model and master the voltage of the neutral point of each node.

The simulation results of this paper will be reflected in the form of phase angle, amplitude, power loss and flow direction of node voltage. It is not only accurately expressed in the form of tables, but also intuitively expressed in graphics. It should be noted that due to some inherent characteristics of DP supply and load fluctuation, the data required for simulation, such as wind speed and light intensity, are obtained in a given time period, and the total number of samples is 500.

In addition to the node voltage, this paper also calculates the power of each line and the total power loss of the system. The following will select branch 32 (27-28) to give its active and reactive PDF simulation graphics. And the PDF graph of the total active and reactive power loss of the system is obtained.

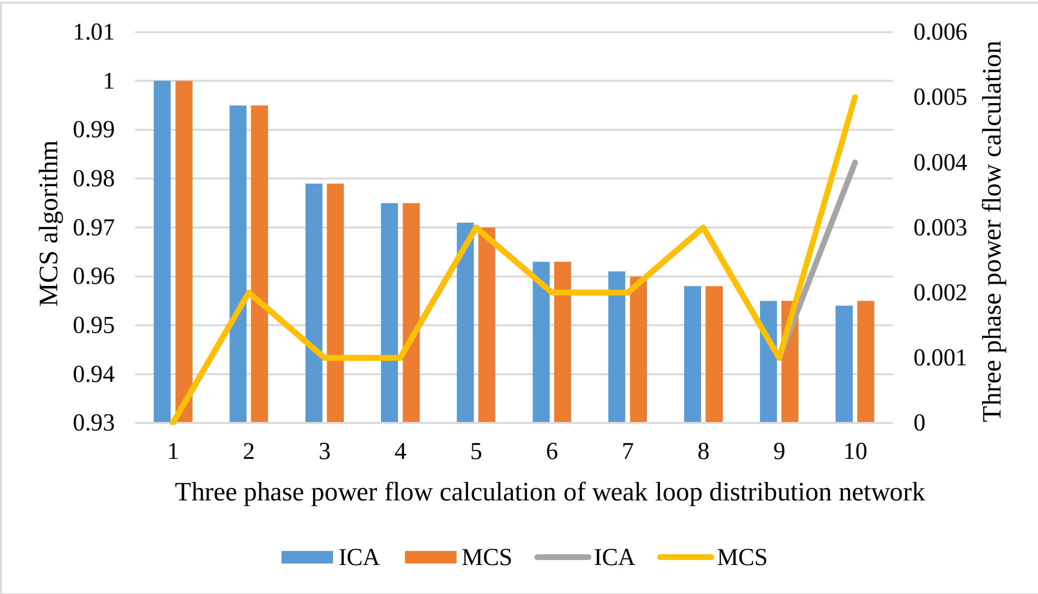

Figure 4. TPPFC of weak LDN with multiple distributed generators

From the above figures and detailed calculation data, it can be seen that the calculation result of TPPF algorithm is very close to that of MCS method, and the error is negligible. However, the calculation time of the TPPF algorithm used in this paper is 348s, which greatly shortens the calculation time compared with the 3746s of MCS method. Moreover, it is suitable for distribution networks with various topologies and has high engineering application value. In addition, TPPF algorithm has unique advantages in calculating high permeability distribution network. At present, the general random power flow algorithm has not been able to effectively calculate the power flow distribution of high permeability power grid, and the TPPF algorithm used in this paper can not consider the system permeability because of its own algorithm characteristics. The future application prospect is very broad.

5. Conclusion

In this paper, power flow analysis and voltage stability research have been carried out after the DG is introduced into the weak ring distribution network. Although good results have been achieved, there are still many aspects that need to be improved and perfected. At the same time, more in-depth research can be carried out on this basis: when the three-phase continuous power flow algorithm is applied to the weak ring distribution network and considering the access of multiple distributed generators, The efficiency and convergence of continuous power flow algorithm will be an important research object; In this paper, the efficiency and convergence are not studied in detail. How to improve the efficiency under the premise of ensuring the convergence of the algorithm will need further research; Due to the limitation of time and other factors, the following aspects need to be further studied in the follow-up research: more effective power flow calculation method, more accurate DG model, rather than just staying in the calculation example.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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